The importance of protected and unprotected areas for the Mediterranean spur-thighed tortoise demography in Northwest Morocco

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ABSTRACT

Collection for the pet trade has been considered one of the major threats to the Mediterranean spur-thighed tortoise *Testudo graeca*, since it modulates the size and structure of the species' populations and, therefore, their demography. Maamora forest is one of the most suitable habitats for this species. The proximity of the forest to Rabat indicated the possibility of these tortoise populations being particularly sensitive to over-collecting. Population demography was studied in four populations, in protected and unprotected areas in Maamora forest. The results showed significant differences as regards population size and structure between protected and unprotected areas. They specifically highlighted: i) higher density (23-17 indiv$\cdot$ha^{-1}) balanced populations in the protected areas, in which young adults were predominant, ii) a higher body condition in the protected areas, especially the females, and iii) a low density (5.5 ind$\cdot$ha^{-1}) more unbalance population in the unprotected areas, in which older females and younger males were predominant. In addition, a survey carried out by interviewing local adults (n=200) showed that most people owned tortoises (61%, n=200), mainly juveniles (65%, n=123). The respondents stated that their tortoises had been captured in the forest (68%, n=123). Maamora forest is home to one of the highest density populations of Mediterranean spur-thighed tortoises documented to date, and its conservation is essential if this species is to be maintained. Our social survey suggested that one of the challenges is to change the social perception of the Mediterranean spur-thighed tortoise as a pet and highlight its intrinsic ecological value.

Keywords: *Testudo graeca graeca*, pet trade, population structure, population size

Introduction

Habitat loss as a result of human activities, such as agriculture, overgrazing and deforestation, in addition to collection for the pet trade, are considered to be the major threats to the Mediterranean spur-thighed tortoise *Testudo graeca* throughout its entire distribution (e.g. Lambert, 1979; Bayley and Highfield, 1996; Pérez et al., 2004; Nijman and Bergim, 2017). The loss of habitats that are suitable for the Mediterranean spur-thighed tortoise in Morocco has been progressive since 1955 and 1969 owing to the decline of both the argan tree and the cork oak tree in forests, mostly as the result of overgrazing (argan tree forest: El Yousfi, 1988; Le Polain de Warot and Lambin, 2011; cork oak forest: Fennane and Rejdali, 2015; Lahssini et al., 2015). In addition, the cutting and clearing practises carried out in order to develop agricultural areas have tended to increase over time, thus reducing nesting sites, making the tortoises more visible to (antropic and natural) predators and increasing their exposure to pollutants. Even the jujube bush has recently suffered from officially promoted removal programmes, which has reduced the microhabitats available for feeding resources and thermal refuges for tortoises (Lagarde et al., 2012; Moulherat et al., 2014).

Morocco has traditionally supplied the European tortoise pet trade, peaking with 100,000 Mediterranean spur-thighed tortoises per year in the sixties (Lambert, 1969). Lambert (1995) observed a decline in their populations of 90% during the period 1900-1984 in some areas in north-western and central Morocco, probably owing, at least in part, to the pet trade. Nevertheless, this species has been protected by CITES since 1975. More recently, in 2008, the illegal importation of 1400 tortoises from North Africa was documented in Sicily (Brianti et al., 2010). Nijman and Bergim (2017) recognised changes in the numbers, in addition to the ages, of the tortoises that were traded in Morocco in 2013-2014 when compared to 2001 (see also Znari, Germano and Macé, 2005), along with higher frequencies of the domestic trade –i.e. exchanges taking place within the boundaries of the country– rather than the export trade tortoises (Lambert, 1979), both of which appear to be affecting the sizes and structures of tortoise populations in the field (Znari, Germano and Macé, 2005).

Despite the interest in Mediterranean spur-thighed tortoises owing to their relatively long reproductive life span, delayed maturity, low hatching success and juvenile survivorship (Díaz-Paniagua, Keller and Andreu, 2001; Ben Kaddour et al., 2006), there is incomplete knowledge regarding the demography of this species in west central Morocco (El Mouden, Slimani and Ben Kaddour, 2002; Slimani, El Mouden and Ben Kaddour, 2002; Znari, Germano and Macé, 2005; Carretero et al., 2005; Ben Kaddour et al., 2006). The species' distribution range in Morocco potentially occupies 167,000 km^2 (Lambert, 1983), and northern Morocco is considered to be close to the optima niche –core range– of the species' distribution (Anadón et al., 2012). Various studies on population structure have already been conducted, mainly in Central Jbilets and the Souss Valley, and more recently in Essaouira (see El Mouden, Slimani and Ben Kaddour, 2002; Slimani, El Mouden and Ben Kaddour, 2002; Carretero et al., 2005; Znari, Germano and Macé, 2005), in which tortoises are at present partially dependant on human influence (already unexploited but years after over-collecting). Differences in population structure have been reported in the three populations highlighted, but the adult class was well represented in all of them and characterised by the lack of older/longer individuals (>226 mm CL). In adddition, intensive demographic studies have been carried in border populations in southeastern and western Spain (Andreu, 1987; Keller, Díaz-Paniagua and Andreu, 1997, 1998), and long-term demographic fluctuations –i.e. a change from a negative to a positive population trend mainly owing to an increase in juvenile recruitment in the last 20-year period– were found in populations that had been under effective protection from human disturbances for 50 years (Díaz-Paniagua, Keller and Andreu, 2001). Long-term monitoring studies have highlighted the regulatory population effect of high juvenile recruitment, in addition to high adult survival rates (Díaz-Paniagua, Keller and Andreu, 2001) and the sex-biased ratios of adults resulting from the human-mediated secondary contact among different lineages (Graciá et al., 2017).

Maamora forest is located in northern Morocco and is the home to Mediterranean spur-thighed tortoises (Lambert, 1983). This was considered the largest single stand of cork oak trees in the world, although it persists now only in the area of the Salé-Kenitra-Tiflet region in which there are plains; its size having decreased from 135,000 ha in 1920 (Emberger, 1939; Boudy, 1958) to 70,383 ha in 2015 (Lahssini et al., 2015). The main cause of the decline in the size of this forest is human pressure (Fennane and Rejdali, 2015; Lahssini et al., 2015). With regard to tortoise populations in this area, its proximity to Rabat (<60 km) and the weekly presence of 5000 cars and 30,000 visitors on sunny days (Fennane and Rejdali, 2015), indicate the possibility that these populations are particularly sensitive to over-collecting (Nijman and Bergim, 2017). In this study, we aimed to: 1) determine the size and structure of tortoise populations located in Maamora forest in order to explore differences between protected (>10 years) and unprotected populations, 2) characterise the use of tortoises as pets in Moroccan society (>18 years old) close to Rabat, and 3) describe the possible influence of the pet trade on the population demography in Maamora forest.

Materials and methods

Study area

The study was conducted in areas of low elevation (72-185 m a.s.l.) and sandy soil in Maamora forest (northwest Morocco; 34º 02’ 54.19’’ N, 6º 27’ 19.24’’ W). The climate is Mediterranean, with hot dry summers and an annual range of average rainfall from 300 to 500 mm. Maamora forest is dominated by cork oak trees, *Quercus suber,* with scattered endemic wild pear, *Pyru mamorensis,* wild olive *Olea europaea*, green olive *Phyllirea latifolia* and mastic *Pistacia lentiscus* and a sparse understory represented by bush and shrub species, such as Mediterranean broom *Genista linifolia, Cytisus arboreus, Stauracanthus genistoides*, dwarf palm *Chamaerops humilis*, French lavender *Lavandula stoechas,* sage-leaved rockrose *Cistus salviifolius* and *Thymelaea lythroides*.

The study specifically took place in four populations that were close together, but always ensuring that the tortoise territories were separated by a sufficient distance (separated by 5 km; Andreu, 1987, Anadón et al., 2006; see also Figure 1). The study populations differed: two of them have been fenced for at least 10 years (hereafter denominated as protected areas; A and B) and are located in a private area, and the other two have no fencing and are for public use (hereafter denominated as unprotected areas; C and D), and might, therefore, be expected to be exploited by the pet trade owing to their proximity to Rabat. The protected areas were characterised by autochthonous bushes (Mediterranean broom and wild olive) and shrubs (dwarf palm, sage-leaved rockrose, French lavender and *Thymeleae*), which were well represented, and a high volume and diversity of herbs. However, non–native bush species (Cactus pear *Opuntiaindica* and Mustard tree *Nicotianaglauca*) and single shrub species (dwarf palm) and a low volume and diversity of herbs covering predominated in the unprotected areas (for further details, see Table 1). The four areas had livestock, mainly cattle and sheep, but differed in terms of livestock densities, and overgrazing was, therefore, higher in the unprotected areas than in the protected ones.

Mediterranean spur-thighed tortoise field study

The study populations were surveyed during the 2017-breeding period, which began at the end of February and continued until the end of May, and inhabited an area covering 12 ha in the case of the protected populations and 17 ha in that of the unprotected ones. Each of the four areas was surveyed for ten days in spring, when male and female detectability is higher (Díaz-Paniagua, Keller and Andreu, 2001; Ben Kaddour et al., 2006;Rouag et al., 2007; Rodríguez-Caro et al., 2016). The tortoises were recorded from 12h until 15h on foot and in adequate weather conditions (sunny days with temperatures of between 20 and 24ºC). In addition, any dead animals found were collected and measured.

The carapace length (mm; CL), body mass (g), sex and age of each of the animals detected were measured as follows. The midline carapace length was recorded using a vernier calliper (accuracy ±1mm) and the body mass using a precise balance (accuracy ±1g). Adults were sexed using classical criteria for Testudinae (Andreu, Díaz-Paniagua and Keller, 2000; Slimani, El Mouden and Ben Kaddour, 2002), assuming a minimum size at maturity of 100 mm for both sexes (El Mouden, Slimani and Ben Kaddour, 2002;Slimani, El Mouden and Ben Kaddour, 2002). Individuals below this threshold were considered to be juveniles and, therefore, the sex was not determined.

With regard to short term monitoring (capture-recapture), the tortoises' carapaces were numbered with non-toxic paint. The capture-recapture procedure assumes a closed population; adult tortoises have a high philopatry and remain localised during breeding (Ben Kaddour et al., 2006).

On the pet trade: interviews and pet shop

In order to characterise the frequency of the use of tortoises as pets and obtain information on their ages and origins, a simple survey based on interviews conducted by an interpreter in the local language was carried out with local people in the areas surrounding the market shops in Rabat in spring 2018. The target group comprised local adults over 18 years of age. The surveys were conducted in the street and consisted of three closed questions: do you currently have or have you had a tortoise in the past? how big was it (juvenile (<100 mm)/adult (>100 mm))? and what was its origin? In those cases in which those being surveyed did not already have or had never had a tortoise in the past, they were asked how they would obtain one in the future (shop, market shop or Maamora forest). Finally, biometric data on tortoises were collected in three trade market shops in Rabat from March to May 2017. The sellers were also asked about the origins of the animals.

Statistical analysis

The tortoises' body condition –i.e. body mass scaled by body size (e.g. Nagy and Medica, 1986; Henen, 1997)– for adults was estimated using residual values obtained by means of linear regression (by sexes), with the natural logarithm (ln) of body mass as the dependent variable and ln CL as the independent variable (e.g. Speakman, 2001). The individual body-condition index expresses the variation in mass in relation to the values expected according to the size of the animal.

Population density estimates of the populations studied were determined by employing the Lincoln-Petersen formula with a Seber (1982) correction (R>7):

$N=((M+1)*(C+1)/(R+1))-1$,

where M is the sample of individuals captured and marked during the first survey, C is the number of individuals captured in the second survey and R is the number of individuals captured during the second survey and already marked.

The differences among the protected and unprotected areas as regards population size were tested by performing the Wald test, with a test statistic W assessed on the Chi-squared distribution with one degree of freedom (Wald and Wolfowitz, 1940). The Chi-square test was also used to assess differences between protected and unprotected areas in terms of population structure (by using size-categories, CL and frequencies). The size distribution of the CL categories 50-99, 100-129, 130-159, 160-189, 190-215 mm were defined according to previous studies with the species (Znari, Germano and Macé, 2005). Finally, the differences between the body condition in protected and unprotected areas were explored with ANOVA, including sex and the interaction between sex and protection status as predictors. All statistical analyses were performed using R 12.1 software (R Development Core Team, 2006).

Results

Two-hundred and eighty-two Mediterranean spur-thighed tortoises were detected in the four populations of Maamora forest: 91 from population A (10 juveniles, 36 males, 45 females; 12 ha), 91 from B (4 juveniles, 37 males, 50 females; 12 ha), 50 from C (3 juveniles, 11 males, 36 females; 15 ha), and 50 from D (7 juveniles, 16 males, 27 females; 20 ha).

Eight dead tortoises were found in three of the four populations: 5 in A (2 juveniles, 2 males, 1 female), 1 female in B and 2 in D (1 juvenile, 1 female). However, it was possible to determine the cause of death of only two tortoises (population A), which was in both cases the result of having been run over by traffic. We also checked 112 tortoises (61 juveniles, 51 adults) in three market shops in Rabat and interviewed 200 local adult people from Rabat.

Population density

The recaptures varied from 7 to 12 (7, 8, 10, 12 in D, A, C and B, respectively). The estimated population size in A was 23.2 indiv·ha^{-1} with a 95% confidence interval (CI) ranging from 10.4 to 36.6 indiv·ha^{-1}; while in B it was 16.6 indiv·ha^{-1} ranging from 8.8 to 24 indiv·ha^{-1}. In the unprotected areas, the population density in C was 5.4 indiv·ha^{-1} with a CI ranging from 2.9 to 7.9 indiv·ha^{-1}, while in D it was 5.5 indiv·ha^{-1} ranging from 2.2 to 8.8 indiv·ha^{-1}. There were significant differences in population density between the protected and unprotected areas (A *vs*. C and D: W= 6.8, p<0.01, n=141; W= 6.6, p<0.01, n=141, respectively; B *vs*. C and D: W= 7.8, p<0.01, n=141; W= 7.2, p<0.01, n=141, respectively).

Individuals' body condition

ANOVA showed that adult body condition varied between the level of protection and the individuals' sex, with the interaction between protection and sex being statistically significant. The effect of protection was greater for females than for males and the tortoises were, in both cases, in better condition in the protected areas (see Figure 3 and Table 3).

Population structure

There was no difference in individual size distribution (CL frequency) between either the two protected populations (A and B; X^2= 4.78, p=0.31, n=182) or the two unprotected populations (C and D; X^2=8, p=0.09, n=100) and they were, therefore, considered as protected (A-B) and unprotected (C-D) areas in the subsequent analyses.
Between 4% and 14% of juveniles were found in both the protected and unprotected areas and no significant differences were found for them as regards their frequency in the afore mentioned areas (X^2=0.593, p=0.44, n=24). The sex ratio –i.e. the number of

females per males– was biased towards the females in the two areas (1.2 in the protected areas and 2.5 in the unprotected areas; X^2= 4.46, $p<0.01$, n=282). The population structure differed significantly in the protected and unprotected populations (X^2=13.74, $p<0.05$, n=282). The main differences concerned the CL size category of 126-155 mm, which represented 38% versus 25% in the protected and unprotected areas, respectively, and that of 185-215 mm, which represented 15% versus 25% in the protected and unprotected areas, respectively.

The frequency distribution regarding the size of both females and males varied significantly between the protected and unprotected areas (X^2=7.85, $p<0.05$, n=168; X^2=17.37, $p<0.05$, n=90, respectively), and the females in the longer size class were represented to a greater extent in the unprotected than in the protected areas, whereas the longer males were represented to a greater extent in the protected than in the unprotected areas. In both the protected and the unprotected areas, the dominant class for females (represented by 60-70%) was >155 mm CL, but the 100-155 mm CL class represented 40% in the protected areas, despite the fact that it was 28% in the unprotected areas. The male dominant class (represented by 65-80%) was conversely 100-155 mm CL in both areas. The largest female in both the protected and the unprotected areas was 215 mm CL (although two females with 230 and one with 270 mm were found in the protected areas in later surveys) (for further details of the mean CL and body mass, see Table 2).

Pet trade

In the social survey, the opinion of 200 adults was obtained, and 61% of the respondents stated that they had a tortoise at the moment of the interview or had previously had one. On average, of the adult people who already had tortoises or had

had them in the past (n=123), only 3% had bought them in a shop. The remaining adults in this category had obtained tortoises as follows: 14% from the market shop, 68% from wild populations and 14% from other people, while 3% had found them in the street (see Table S1, Supplementary Material). The tortoise population in captivity was mainly represented by juveniles (65%, n= 123). Similarly, of the adult people who did not have tortoises (n=77), only 8% stated that they would buy one in a shop and 21% from the market shop, while 71% would obtain one from wild populations. With regard to the same respondants, 45% of them had no preference, as regards the age of the tortoise, but 44% would prefer juveniles.

In the market shops in Rabat, the largest number of tortoises (54%, n=112) corresponded to <100 mm CL (very few from the first year, 2%); 38% had a 100-160 mm CL and 8% had a >161 mm CL.

Discussion

Significant differences in population size, population structure and body condition were found for the populations of Mediterranean spur-thighed tortoise in the protected (>10 years) and unprotected areas in Maamora cork oak forest. Whereas high densities and a balanced population structure were associated with the protected areas, the unprotected ones were characterised by low densities and predominantly older females and younger males, both of which had a lower body condition. The capture of Mediterranean spur-thighed tortoises for the pet trade, which, according to a survey of local people, reflects the high number of animals collected from wild populations in Maamora, pinpoints this threat as a possible driver modulating demographic population parameters in unprotected areas.

Population density and individuals' body condition

The population density in the protected areas in Maamora (17-23 indiv·ha^{-1}) was higher than values reported for other protected populations throughout species distribution (e.g. Andreu, Díaz-Paniagua and Keller, 2000; Slimani, El Mouden and Ben Kaddour, 2002; Ben Kaddour et al., 2006; Ballestar et al., 2004; Anadón et al., 2007; Rodríguez-Caro et al., 2017; Rouag et al., 2007) and three or four times higher than those observed in the unprotected areas (5.5indiv·ha^{-1}) of Maamora. These differences between the protected and unprotected populations in Maamora evidence threats to the unprotected populations, the more plausible causes being the pet trade (Lambert 1979;Pérez et al., 2004; Znari, Germano and Macé, 2005; Brianti et al., 2010; Nijman and Bergim, 2017) and habitat alteration (Bayley and Highfield, 1996; Slimani, El Mouden and Ben Kaddour, 2002; Anadón et al., 2007). Habitat quality, which was lower in unprotected areas owing to human disturbances, such as livestock overgrazing, dwarf palm and cork oak harvesting and agricultural practices, may be the principal cause of these differences. Indeed, competition for food between tortoises and mammals is expected in overgrazed areas, and harvesting and agricultural practices might favour a lower availability of refuge cover (El Mouden et al., 2006). However, it is probable that habitat quality cannot be considered as the sole cause, since the pet trade might also play a role as regards explaining differences in density between protected and unprotected areas. Futher studies are, therefore, required so as to discover the relative role of each factor in order to design efficient actions for species conservation.

Adult body condition was higher in the protected areas when compared to the unprotected ones, particularly in the case of females. This finding might be explained by the lower extent of scrub cover and height resulting from the long-term effect of livestock in unprotected areas (Fennane and Rejdali, 2015), which probably reduces the availability of food resources and perturbes thermoregulation, thus causing excessive energy expenditure and consequently reducing body condition (e.g. Esque et al., 2003). The consequences of a lower female body condition at the onset of the breeding seasons might influence the decision to reproduce, the mobilisation of maternal reserves and post-reproduction survival, and, therefore, have a high potential to regulate population demography in general and population density in particular.

Population structure

Most of the captures in the protected areas in Maamora were similar to those that took place in d`El Kala National Park in Algeria as regards population structure, where young adults were predominant (140-190 mm CL; Rouag et al., 2007), but differed from those of Central Jbilets and Essaouira in Morocco (90-170 and 110-210 mm CL, respectively; Znari, Germano and Macé, 2005). Nevertheless, most captures in the unprotected areas in Maamora differed from the protected ones as regards the more unbalanced size structure, which was evidenced by the dominating longer and older females (>155 mm CL) and shorter and younger males (<155 mm CL) in the unprotected areas, in which they represented 80% of the population. In addition, the lack of larger and older tortoises (>216 mm CL), such as the females reported in Admine (226 mm) and Tagourat (255 mm) (Znari, Germano and Macé, 2005), might indicate the possibility of a previous souvenir trade years ago in the unprotected areas of this cork oak forest (Lambert, 1979, 1984; Highfield, 1994).

In addition, while female sex-biased ratios occurred in declining *Testudo* populations, balanced sex ratio populations can be considered as typical of stable populations (*T.hermanni,* e.g. Cheylan et al., 2010). Indeed, the adult sex ratio is expected to influence sex roles and breeding systems, as the rarer sex in the population has more potential partners to mate with than the more common sex (Szekely, Weissing and Komdeur 2014). The protected Maamora areas were slightly female-biased (1.2), which differed from the other Mediterranean spur-thighed tortoise populations documented, such as those of Doñana (0.71;Díaz-Paniagua, Keller and Andreu, 2001), Central jbilets (0.83-1; Znari, Germano and Macé, 2005; Ben Kaddour et al., 2006) and Admine (0.6; Znari, Germano and Macé, 2005). Nevertheless, female bias had been documented in other *Testudo* populations of Spain, France and Sardinia (*T. hermanni;* Bertolero 2015; Cheylan et al., 2011; Biaggini et al., 2018). Bearing in mind that detectability might vary between years, and the fact that our study comprised one year, the populations were strongly female-biased (2.5) in the unprotected Maamora areas. According to the low male mortality found, which did not appear to be different from the female mortality, as was found in southern Spain populations (Díaz-Paniagua et al 2001), it is possible that sex-differential juvenile mortality leads to a biased sex ratio at maturation (Szekely, Weissing and Komdeur 2014). But higher temperatures could also play a role in the female-biased sex ratio, as this species has a temperature-dependent sex determination (Pieau 1975). Long-term monitoring of these valuable populations will, hopefully, shed light on these issues.

Population structure might modify demographic parameters, such as fecundity, juvenile recruitment and growth rate, and subsequently influence genetic and ecological variations among individuals (e.g. Rudolf and Rasmussen, 2013). In our study, there were fewer juveniles in both the protected and unprotected areas (4-14%) than in Doñana (13-26%, Díaz-Paniagua, Keller and Andreu, 2001) and Central Jbilets (23%, Znari, Germano and Macé, 2005). The percentages found were, however, fairly similar to those of Algeria (6%, Rouag et al., 2007), Admine or Essaouira (10% and 8% respectively, Znari, Germano and Macé, 2005). In this respect, the local people interviewed who had obtained tortoises from wild populations in Maamora (the main origin of the tortoises), showed a higher preference for juvenile tortoises than for adults. Moreover, the most suitable means of adquiring a tortoise in the future for those people who did not already have one, was also wild populations from the forest, showing the potential relevance of the pet trade in the unprotected areas close to Rabat. However, if the pet trade is responsible for the low frequency of juveniles, then juveniles should be observed to a greater extent in protected rather than in unprotected areas, but this was not the result we attained. This signifies that the pet trade is not the sole cause of the low rate of juveniles in our study area. In this respect, it is necessary to discover the roles played by predation risk, refuge cover or food resources in juvenile mortality rates in Maamora populations. Long-term studies are, therefore, required in order to assess hatchling and juvenile survival and their variation over time.

Conservation

Maamora forest is home to one of the highest density populations of Mediterranean spur-thighed tortoise documented to date, and the conservation of this forest is essential if this species, along with a wide variety of other species of birds (Cherkaoui et al., 2009; Segura et al., 2017) and plants (Aafi, 2007), are to be maintained. Nevertheless, this Mediterranean forest is under pressure from forestry practises (Fennane and Rejdali, 2015), intense overgrazing by livestock and the leisure activities of human inhabitants (Lahssini et al., 2015). These issues are consequently already affecting the Mediterranean spur-thighed tortoise in terms of population density, individuals' body condition and population structure in unprotected areas by reducing the scrub, which is a thermal refuge, feeding and nest site area (El Mouden et al., 2006, Moulherat et al., 2014), and is thus favouring its risk of visibility, predation and catchability (Ben

Kaddour et al., 2006). But even more importantly, the presence of humans in Maamora each weekend has led the Mediterranean spur-thighed tortoise to concentrate in less suitable areas in terms of feeding and refuge (Bayley and Highfield, 1996; Slimani et al., 2001), and human contact with wild tortoise populations might be favouring the removal of this species from the forest to be kept as pets. This was reinforced in our interviews with local people in Rabat, as was found in southern Spain (Perez et al., 2004), where keeping tortoises in captivity has been proved to be a long-established custom. One of the challenges is, therefore, to change the social perception of the Mediterranean spur-thighed tortoise as a pet and to highlight its intrinsic ecological value as a long-living wild species that inhabits threatened habitats of great interest that must be protected.

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Tables

Table 1. Vegetation richness, height (cm) and surface cover (%) and livestock (LSU/ha) in the four populations studied. Data regarding livestock in the unprotected populations were obtained from Laarybia et al. (2014).

	A	B	C	D
Herbrichness	20	18	9	11
Herbheight	40-80	40-100	<10	<20
Herbcover	18	18	55	55
Shrubrichness	5	5	1	1
Shrubheight	20-120	20-120	20-40	20-40
Shrubcover	50	50	25	25
Bush richness	3	1	1	1
Bush height	80-200	80-120	150	100-180
Bush cover	30	20	5	5
Baregroundcover	2	2	15	15
Livestock	1.2	1.2	6.4	6.4

Table 2. Mean carapace length (CL) and mass of male (M), female (F) and juvenile (J) Mediterranean spur-thighed tortoise in the four natural populations studied (±SD), two protected (A and B) and two unprotected (C and D).

		CL (mm)	Mass (g)
	J (n=7)	67±22.18	99±76.87
	M (n=36)	158±2.27	771±316
A	F (n=45)	154±2.59	731±334
B	J (n=3)	74±21.12	99±54.60

	M (n=37)	156±3.03	782±359
	F (n=50)	161±3.08	850±388
	J (n=4)	79±17.82	135±64.78
	M (n=11)	148±1.98	666±236
C	F (n=36)	172±2.89	1034±415
	J (n=16)	74±13.63	101±45.08
	M (n=16)	151±1.88	665±276
D	F (n=27)	173±3.27	1031±446

Table 3. Results of ANOVA explaining the variation in tortoise body condition in relation to sex (M male, F female) and human influence (P protected vs. U unprotected area).

Modelpredictors	Estimate	Std error	Z value	P value
Protection (U)	-0.0332	0.063	-5.337	<0.05
Sex (M)	-0.0156	0.005	-2.619	<0.05
Sex(M)*Protection(U)	0.0217	0.01	2.044	<0.05

Figure legends

Figure 1. Distribution of *Testudo graeca* adapted from Giménez et al. (2005). Location of the study area and tortoise populations studied is shown.

Figure 2. Structure population based on carapace length (mm) of the four populations of Mediterranean spur-thighed tortoise (frequency of females shown in black and that of males in grey).

Figure 3. Distribution of adult body condition according to sex (female [F] and male [M]) and human influence (unprotected [U] and protected [P]).

Supplementary material

The importance of protected and unprotected areas for the Mediterranean spur-thighed tortoise demography in Northwest Morocco

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Table S1. Results of the social surveys carried out in Rabat. Tortoise origin and age class (juvenile/adult) obtained from the tortoise owners and tortoise preference (origin and age (juvenile/adult/no preference) from people without tortoises (not tortoise owners).

		Origin					Age class		
	n	Forest	Market	Shop	People transfer	Street	Juvenile	Adult	No preference
Tortoise owner	123	77	17	4	18	7	80	43	0
Not tortoise owner	77	55	16	6	0	0	34	8	35

Figures

Figure 1. Distribution of *Testudo graeca* adapted from Giménez et al. (2005). Location of the study area and tortoise populations studied is shown.

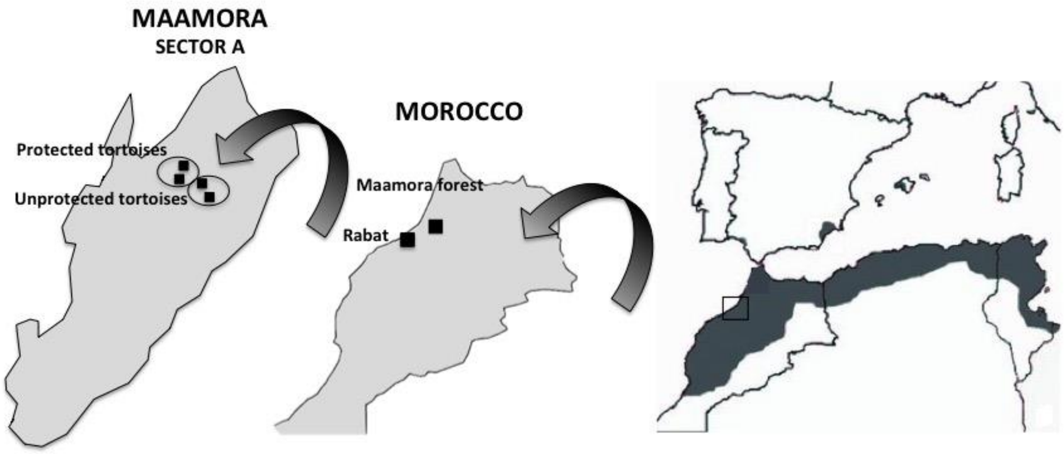

Figure 2. Structure population based on carapace length (mm) of the four populations of Mediterranean spur-thighed tortoise (frequency of females shown in black and that of males in grey).

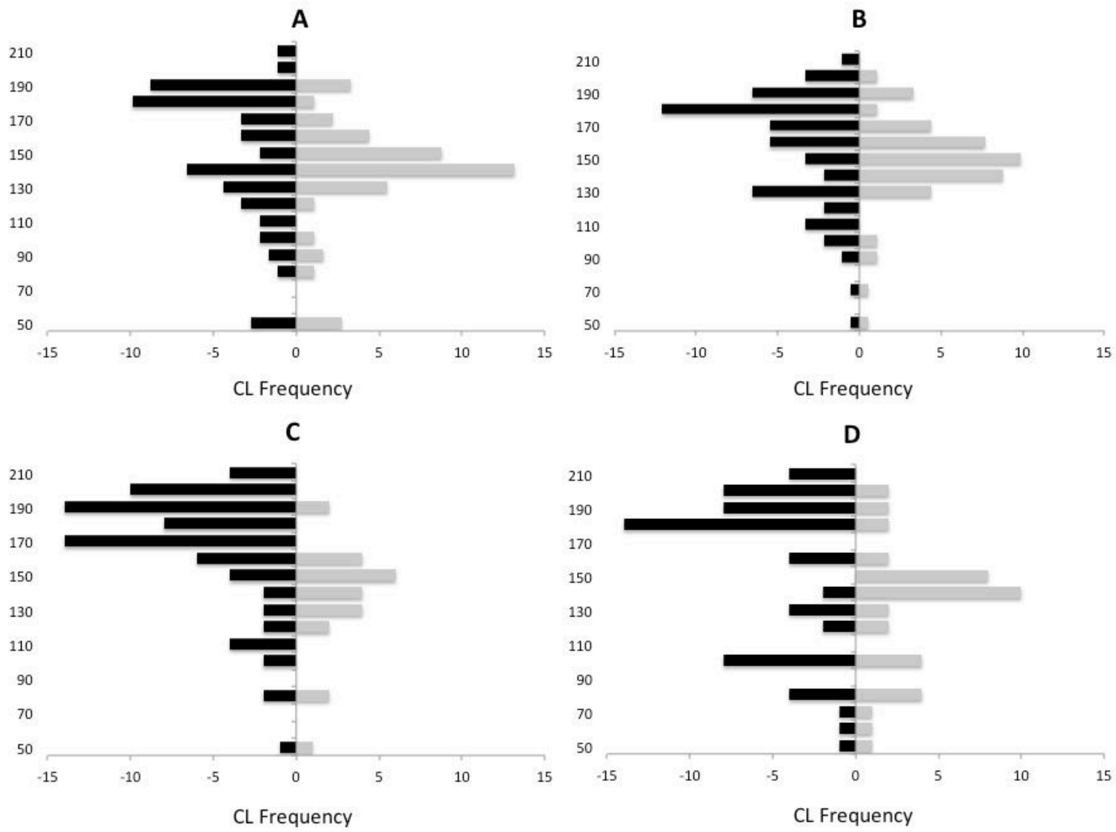

Figure 3. Distribution of adult body condition variations according to sex (female [F] and male [M]) and human influence (unprotected [U] and protected [P]).